

SIMULATION TEST OF AUTOMOTIVE ALLOY WHEEL USING COMPUTER  
AIDED ENGINEERING SOFTWARE

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MOHD IZZAT FALIQFARHAN BIN BAHAROM

A report submitted in partial fulfillment  
of the requirements for the award  
of the degree of  
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## **ABSTRACT**

This paper will present and discuss the use of finite element technique for simulation test of functionality of automotive alloy wheel nature during operation. Computer Aided Engineering Software is used to simulate the wheel through loading method. Several common design of wheel that is been used in the automotive industry is used. The load for stress distribution and displacement data subjected to loading on alloy wheel is viable through the finite element model. The result shows critical point takes places at certain point of the alloy wheel component

## **ABSTRAK**

Projek ini akan menerangkan dan membincangkan penggunaan teknik finite elemen untuk ujian simulasi bagi penggunaan roda aluminum semasa operasi. Software komputer bantuan kejuruteraan digunakan untuk simulasi melalui kaedah beban. Rekaan spesifik bagi roda aluminum yang biasa digunakan dalam industri automotif digunakan untuk projek ini. Beban untuk terikan dan sesaran apabila dikenakan beban pada roda aluminum ditunjukkan melalui model teknik elemen finite. Keputusan menunjukkan lokasi kritikal yang berlaku di poin tertentu di komponen roda aluminum

### **STUDENT'S DECLARATION**

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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To my beloved mother and father

**Mr. Baharom Bin Abdul Ghani**

**Mrs. Norma Bt Taib**

And my brother and sisters

## **ABSTRACT**

This paper will present and discuss the use of finite element technique for simulation test of functionality of automotive alloy wheel nature during operation. A specific design wheel is used. The load for stress distribution and displacement data subjected to loading on alloy wheel is viable through the finite element model. The result and how wheel performed is discussed.

## **ABSTRAK**

Projek ini akan menerangkan dan membincangkan penggunaan teknik finite elemen untuk ujian simulasi bagi penggunaan roda aluminum semasa operasi. Rekaan spesifik bagi roda aluminum digunakan untuk projek ini. Beban untuk terikan dan sesaran apabila dikenakan beban pada roda aluminum ditunjukkan melalui model teknik elemen finite. Keputusan dan bagaimana roda itu dijalankan dibincangkan dalam projek ini.



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## LIST OF ABBREVIATIONS

CAD	Computational Added Design
3D	Three Dimensional
kPa	Kilo Pascal
mm	Millimeter
kN	Kilo Newton
MPa	Mega Pascal
W	Work
Rb	Bead radius

## CHAPTER 1

### INTRODUCTION

#### 1.1 Introduction

The wheel is a device that enables efficient movement of an object across a surface where there is a force pressing the object to the surface. Early wheels were simple wooden disks with a hole for the axle. Because of the structure of wood a horizontal slice of a trunk is not suitable, as it does not have the structural strength to support weight without collapsing; rounded pieces of longitudinal boards are required. The spoke wheel was invented more recently, and allowed the construction of lighter and swifter vehicles. Alloy wheels are automobile wheels which are made from an alloy of aluminum or magnesium metals (or sometimes a mixture of both). Alloy wheels differ from normal steel wheels because of their lighter weight, which improves the steering and the speed of the car, however some alloy wheels are heavier than the equivalent size steel wheel. Alloy wheels are also better heat conductors than steel wheels, improving heat dissipation from the brakes, which reduces the chance of brake failure in more demanding driving conditions. Over the years, achieving success in mechanical design has been made possible only after years of experience coupled with rigorous field-testing. Recently the procedures have significantly improved with the emergence of innovative method on experimental and analytical analysis. Alloy wheels intended for normal use on passenger cars have to pass three tests before going into production: the dynamic cornering fatigue test, the dynamic radial fatigue test, and the impact test. Many alloy wheels manufacturing company had done numerous amount of testing of their product but their method on simulation test on alloy wheel information often kept limited.

Historically, successful designs was arrived after years of experience well aided worth extensive field -testing. Since the 1970's several innovative methods of testing and experimental stress measurements have been initiated. In more recent

years, the procedures have significantly improved by the emergence of a variety of experimental and analytical methods for structural analysis. Durability analysis, that is: fatigue life prediction and reliability methods, for dealing with various inherent in engineering structures has been used for the study of automotive rims.

In its basic form a wheel is a transfer element between the tire and the vehicle. The function of a wheel can be further broken up into simple verb-noun combinations to describe its purpose. A wheel;

- i.     ♦ Transfers torque, (braking and acceleration)
- ii.    ♦ Support mass, (support the mass of the motor vehicle)
- iii.   ♦ Adds mass, (damped mass for driving comfort)
- iv.     ♦ Dissipates heat, (from braking)
- v.      ♦ Adds value, (aesthetically pleasing)
- vi.     ♦ Absorbs impact, (road hazards)
- vii.   ♦ Conserves energy, (potential energy in momentum)

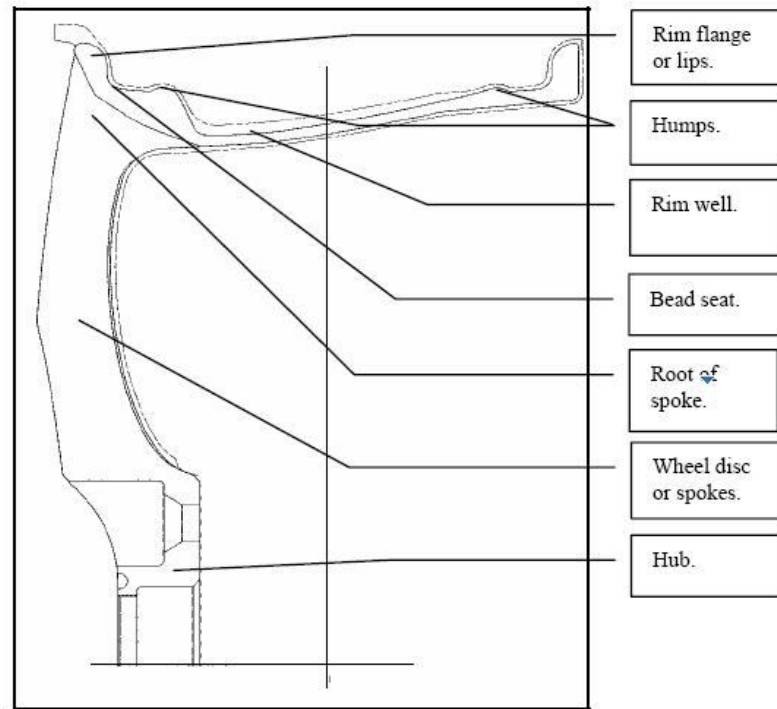


Figure 1: Wheel Assembly

**i. Hub**

This forms the interface between the hub of the vehicle's drive train and the wheel. This part will have the bolt holes to facilitate in the fastening of the wheel to the vehicle.

**ii. Wheel disc or spokes**

This is the part of the wheel that transfers all of the loads.

**iii. Rim flange or lips**

These lips retain the tire and also act as a strength-rib to protect the wheel against impact loads.

**iv. Bead seat**

The tire bead will rest against this area.



**v. Humps**

These humps will ensure that the tire stays against the rim flange in the deflated condition.

**vi. Rim well**

This area facilitates in the assembling and disassembling of the tire.

## **1.2 Problem Definition**

This project will be focus on simulating the nature of alloy wheel during operation on road. A range of variables and parameter will be accounted in the simulation. These testing methods provide information on the stress analysis of the alloy wheel in different situation when loads are acted on different design of alloy wheels. Stress occur on the rim under radial load determine the performance characteristic of an alloy wheel for structural integrity. A wheel should maintain structural integrity without any cracks or plastic deformation. Under a radial load, the strength of the rim usually determines the fatigue life of a wheel, so the stress evaluation is mainly focused on the rim.

### **1.3 Objectives**

Objectives of the project are:

- i. To simulate the stress analysis of alloy wheel using computer aided engineering software
- ii. To studies the stress analysis distribution occurs of an alloy wheel when static force is acted on.

### **1.4 Scopes**

The scopes of the project are:-

- i. Design of the automotive alloy wheel using CAD software product is generally used in automotive industry (14, 15, 16 inch alloy wheel, 6 inch wide, 5~8 spokes)
- ii. Simulation data collection using FEA software
- iii. Analysis of stress analysis of alloy wheel

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Loading Methods on Automotive Wheel.

Presented here are several methodologies for modeling the effect of the vehicle weight as it is transferred to the rim. Methods explained are referenced in the published literature and analogies taken from thick ring theory in stress analysis in the development of loadings on links and eyebars. As stated, the modeling of the tire on the rim is extremely complex and involves both non linear analysis (tire portion) coupled with linear static stress analysis (rim). The interface of the two components would be achieved by the use of gap or contact elements. This work has been done at The Goodyear Tire and Rubber Company. Results indicate that the loading shape is in the form of a cosine function about a central angle of about  $30^\circ$  from either side of the point of contact with the ground.

Others assumed this  $30^\circ$  angle is developed from the contact patch geometry of the tire. Meaning that when the tire is loaded there is flat at the point of contact with the ground, this is the so called contact patch, and the length of this patch is then converted to an angle swept by the bead seat area in contact with the rim. The other bead seat areas tend to be pulled away from the rim, so no loading is present in the areas or is considered negligible.

Finally, a method proposed assumes the area in contact with the rim spans half of the tire or  $90^\circ$  symmetrical about the point of loading. The loading method is similar to a cylindrical bar in a clevis, assuming no gap exists.

The total weight of a car is balanced with a vertical reaction force from the road through the tire. This load constantly compresses the wheel radially. While the car is running, the radial load becomes a cyclic load with the rotation of the wheel. Hence, the evaluation of wheel fatigue strength under radial load is an important performance characteristic for structural integrity. According to the SAE, a wheel should maintain structural integrity without any cracks or plastic deformation for more than  $4 \times 10^9$  rotations under a radial load,  $Q$ , expressed by the following equation.

$$Q S_r * W \dots \dots \dots = (1)$$

where,  $S_r$  means acceleration test factor ( $S_r = 2.2$ ) and  $W$  means maximum tire load. For this application  $W = 4316$  N, thus  $Q = 9496$  N.

Under a radial load, the strength of the rim usually determines the fatigue life of a wheel, so the stress evaluation is mainly focused on the rim. In this analysis also, the contact condition between the discs spoke flange and the rim well is assumed to be tightly closed, and the contact area is modeled by one element with the summed thickness of the disc and the rim.

In an actual wheel, since a radial load is applied to the wheel on the bead seats with the tire, the distributed pressure is loaded directly on the bead seats of the model in this analysis. The pressure is assumed to have a cosine function distribution mode within a central angle of  $40^\circ$  in a circumferential direction as shown in Figure 3. The  $40^\circ$  was chosen based on previous literature, in which some determined this angle by strain gauge experiments or some researchers assuming the angle from the contact patch area. Using the idea of the contact patch width corresponds to the area of contact over the bead seats as shown in Figure 2.

This may not be valid for the run flat tire due to its stiff side walls, which would reduce the contact patch area. According to the manufacturer, a run flat tire deflects about 12 mm for every 4448 newtons of force; The P22560R16 tire under the load of 10.45 kN, the tire should deflect 29.71 mm. This is in good agreement with the experimental tests that predicted 8.9 mm at 3113 N load. For a corresponding height of 29.71 mm and based on a tire diameter of 663 mm, the angle  $\theta$ , swept out is 48 degrees. The calculations were based on segments of circle geometry. This analysis however did not prove to be entirely accurate and was later found to be almost  $90^\circ$ . This can be rationalized, because of the additional strength needed in the bead seat area of the tire. By using the cosine function accordingly, the distributed pressure,  $W_r$ , is given by the following equation:

$$W_r = W_0 * \cos\left(\frac{\pi}{2} * \frac{\theta}{\theta_0}\right) \dots\dots\dots(2)$$

The total radial load  $W$  is calculated by using Eq. (2) as follows.

$$W = b \int_{-\theta_0}^{\theta_0} W_r * r_b d\theta \dots\dots\dots(3)$$

$$W = b \int_{-\theta_0}^{\theta_0} W_0 * r_b * \cos\left(\frac{\pi}{2\theta_0} * \theta\right) d\theta$$

$$W = b * W_0 * r_b * \left[ \frac{1}{\frac{\pi}{2\theta_0}} \right] * \sin\left(\frac{\pi}{2} * \frac{\theta}{\theta_0}\right) \Bigg|_{-\theta_0}^{\theta_0}$$

$$W = 4 * b * r_b * \theta_0 * \frac{W_0}{\pi} \dots\dots\dots(4)$$

or

$$W_0 = \frac{W * \pi}{b * r_b * 4 * \theta_0}$$

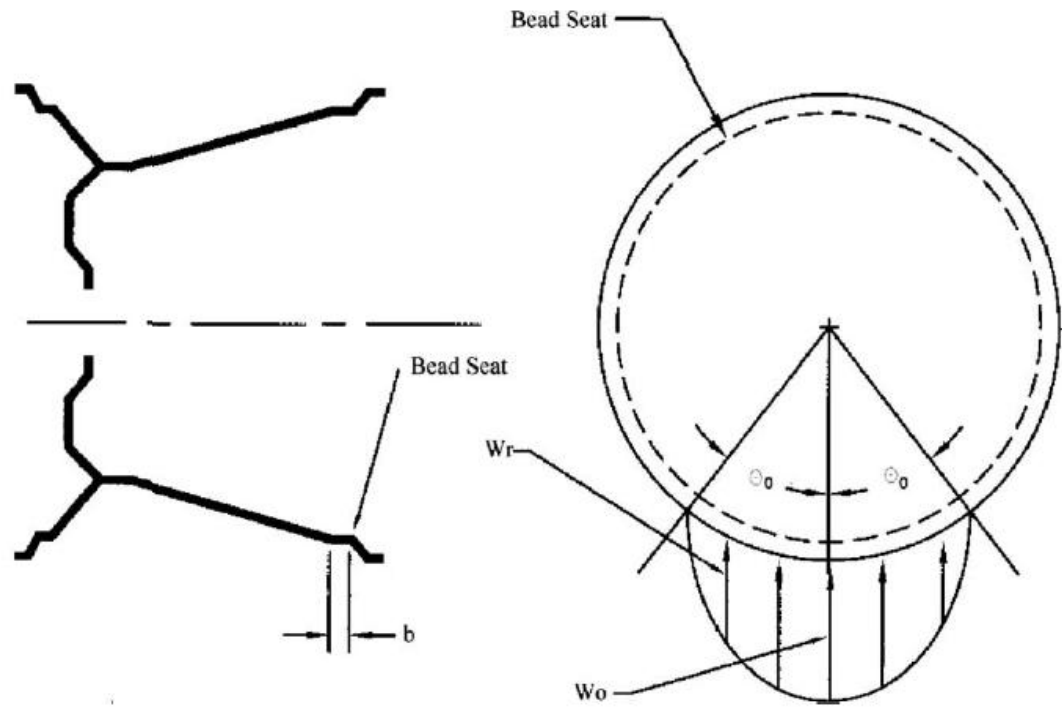
b=19.8 mm, W=10.4 kN , r<sub>b</sub>=7202 mm. Applying these yields W<sub>0</sub> = 2045 kPa. where, r<sub>b</sub> is the radius of the bead seats and b means the total width of the bead seats. In this analysis, the total radial load W = 9496 N is applied to the model, and the magnitude of the load is the same as applied to the actual wheel in the stress measurement experiment.

In this stress measurement experiment, the wheel is assembled with a Goodyear Eagle aqua steel tire (P22560R16) which is inflated to a pressure of 241 kPa and pressed against a flat plate with a load of 3113 N. Strain gages are attached to the wheel in circumferential direction. The central angle 0° of the pressure distribution is 80 degree.

Pressure is applied to two bead seats on the inboard side and the outboard side. In detail, half of the pressure on the inboard side is applied to the inboard rim flange, and the other half is applied to the inboard bead seat. The reason for this is that the inboard rim flange deflects easily due to the long inboard rim leg, and so it is susceptible to loading from the tire. The loading condition described above is determined from a comparison between the measured stress of the rim and the calculated stress under some tentative loading conditions.

The optimum dividing ratio of the applied load on the bead seat versus the applied load on the rim flange is thought to vary according to the contact condition between the tire and the rim. This, in turn, is affected by such factors as tire type (bias or radial), the tire air pressure, the reinforcement structure of the tire and the type of the rim [2]. In actual modeling the locations along the circumference were identified as element numbers (node numbers) and corresponding angle.

Previous experiment results on this subject have revealed that the actual load on the tire-rim unit takes the form of a cosine function having a central angle of about  $40^\circ$  measured from either side of the point of contact with the ground (Figure 2)[1-3]. Subsequent research efforts have confirmed the  $40^\circ$  angle and attributed it to contact patch geometry of the tire [4]. This essentially implied that when the tire is fully inflated there occurs a flat at the point of contact with the ground. This is referred to as the contact patch. The length of the contact patch is converted to an angle swept by the “bead seat” area in contact with the rim. Other bead seat areas tend to be pulled away from the rim, and no loading is assumed to be present in these areas. The method used in this study assumes that the area in contact with the rim spans half of the tire, i.e.,  $90^\circ$  symmetrical about the point of loading. The loading method is quite similar to a cylindrical bar in a clevis and assuming the lack of a gap. This method is referred to as the eyebar loading method [5]. This stress and displacement of the experiment only limited to the bead seat of alloy wheel.



**Figure 2.1:** Radial load on Wheel

## 2.2 Material properties and manufacturing process for cast aluminum wheels

One of the leading aluminum alloys for wheels in use today is AlSi7Mg, with the chemical composition shown in Table 2.

Si	Fe	Cu	Mn	Mg	Zn	Ti
6.5–7.5	0.15	0.03	0.10	0.3–0.45	0.07	0.10–0.18

**Table 2.1:** Chemical composition of AlSi7Mg (in %)